Algorithm for Symmetrical Fault Calculation in Power System Transmission Lines

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Abstract- This paper proposes a symmetrical short circuit current calculation algorithm in power systems transmission lines. The method consists of adding a fictitious node in the power system, located at the point where it is required to calculate the fault in the transmission line, and is defined as a percentage taking as a reference the line sending node. Once the fault point is specified, the systematic fault analysis of the power system is carried out using the Z-bar matrix. The algorithm's reliability and accuracy are demonstrated through a case study with a 5-node test power system and a real equivalent system of 39 nodes. The results of the study cases show that the proposed algorithm is reliable and accurate for calculating or simulating symmetrical faults in power systems transmission lines.

Index Terms- Algorithm, symmetrical fault, power system, transmission line.

I. INTRODUCTION

The continuity of power supply to loads connected to the power system depends on the operational capacity of electrical protections, as they must function correctly during fault occurrences to safeguard the power system. To achieve this, such protections must be capable of withstanding the short-circuit level present at the fault location and isolating the circuit under fault. Symmetrical faults also known as balanced three-phase faults are the least common but the most severe in power systems [1].

It is widely recognized that power systems experience both symmetrical and asymmetrical faults caused by various factors. Numerous studies and algorithms have been reported in the literature for calculating fault currents in substations [2-4] or during power oscillations [5-7]. Regarding fault analysis in transmission lines, most research has focused on fault detection, classification, and location using different methodologies and algorithms [8-12]. Additionally, some studies have analyzed compensated transmission lines, including the integration of FACTS devices [13, 14]. However, it should be noted that very few algorithms specifically target fault analysis in transmission lines. Notable examples include the Reactance Algorithm, Phadke's Algorithm [15], Novosel's Algorithm [16], and the Reactance and Takagi Algorithm [17]. It is also important to emphasize that most commercial and specialized software for short-circuit analysis does not implement tools for fault calculation in transmission lines.

For this reason, developing and implementing a computational algorithm capable of calculating and locating symmetrical faults along transmission lines is essential. This would provide critical information for sizing circuit breakers, coordinating protection systems, and determining the fault location—and consequently, its causes—along the transmission line [1].

II. SYMMETRICAL FAULT ANALYSIS

A symmetrical or three-phase fault occurs when there is a short circuit in the three phases of an electrical system equipment. Since the system remains balanced during this fault, it is possible to carry out its analysis by phase. The algorithm proposed in this work uses the systematic fault analysis based on the bus impedance matrix, which is expressed by means of the following expression:

$$\begin{bmatrix} V_{F1} \\ \vdots \\ V_{Fk} \\ \vdots \\ V_{Fn} \end{bmatrix} = \begin{bmatrix} V_1 \\ \vdots \\ V_k \\ \vdots \\ V_n \end{bmatrix} - \begin{bmatrix} Z_{11} & \cdots & Z_{1k} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{k1} & \cdots & Z_{kk} & \cdots & Z_{kn} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nk} & \cdots & Z_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ \vdots \\ I_{Fk} \\ \vdots \\ 0 \end{bmatrix} \tag{1}$$

Where the fault current or short-circuit level at bus k of the power system is,

$$I_{Fk} = \frac{V_k}{Z_k + Z_{kk}} \tag{2}$$

Once the fault voltages at the system nodes are known, it is possible to know the fault currents occurring in the transmission lines using the following expression,

$$I_{Fij} = \frac{V_{Fi} - V_{Fj}}{Z_{ij}} \tag{3}$$

III. PROPOSED ALGORITHM FOR THE SYMMETRICAL FAULTS CALCULATION IN POWER SYSTEM TRANSMISSION LINES

The proposed algorithm is based on adding a fictitious node to the power system, positioned between the sending and receiving nodes at a certain distance, expressed as a percentage, from the sending node of the line where the symmetrical fault is to be calculated, as illustrated in Fig. 1. Thus, the sending node serves as the reference point for measuring the fault location along the transmission line. This is achieved by establishing a percentage-based equivalence between the distance and the series impedance of the line. For instance, if the fault location is at 50% of the total distance of the line, the series impedance viewed from the sending node will be 50% of the total series impedance of the line. Thus, the percentage of the total line distance will be equivalent to the same percentage of the series impedance as shown:

$$\%Z_{serie} = (\%\text{ distance})(R_{total} + jX_{total}) \tag{4}$$

It is evident that if the distance is 0% or 100%, the fault occurs at the sending or receiving node, respectively. It is essential to note that the proposed algorithm allows for locating symmetrical faults at any point along the transmission lines of a power system line.

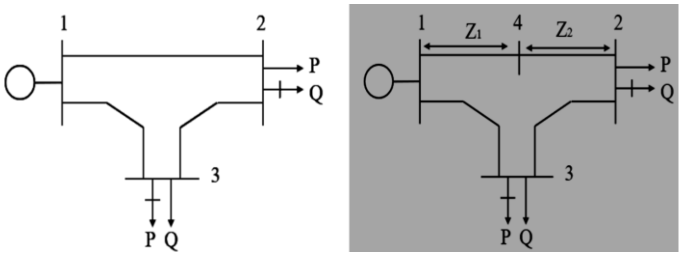

Fig. 1. 3-node power system with and without additional fault node.

In this way, when the total distance of the transmission line is not known, the series impedance is divided by the percentage of the distance in which the fault is to be calculated. In that percentage of distance, the new node where the fault is to be calculated is located. Thus, the transmission line is always divided into two parts, as illustrated in Fig. 1, considering the fault location point as a new node in the power system so that the system will have an additional node and line. Once the location of the new node is defined, the systematic fault analysis is carried out using the bus impedance matrix.

IV. STUDY CASES

In order to illustrate the reliability of the proposed algorithm for the symmetrical faults calculation in power transmission lines, two case studies are carried out with the IEEE 5-node [18] and New England 39-node [19] test power systems, simulating three-phase faults at different percentages along a power system line.

A. Study case: IEEE 5-node test power system

In this case study, a new node is incorporated into the power system to calculate symmetrical faults along transmission line 5-4 at 20% intervals of its total length, ranging from 0% to 100%. It should be noted that a fault occurring at 0% of the line length corresponds to a fault at the sending node, while a fault at 100% indicates a fault at the receiving node. For all fault locations along the percentages of the line length, a fault impedance of 0.16j pu is considered. The results of the symmetrical fault analysis on line 5-4 are presented in Table 1.

Table 1. Symmetrical fault current on transmission line 5-4 at different distance percentages.

Line length (%)	Magnitude I_F (pu)
0	2.7603
20	2.7499
40	2.7416
60	2.7354
80	2.7313
100	2.7293

In the previous table, the fault current phase angle is 90°, which aligns with Eq. (2) because the resistance of the transmission elements of the power system is neglected. In other words, by disregarding the resistance, there is no real component, leaving only the reactance or the imaginary part of the impedance in the power system topology, resulting in an impedance with a 90° angle.

The results presented in Table 1 are graphically illustrated in Fig. 2 to better visualize the behavior of faults at different distances along the transmission line. This figure shows that the fault current level decreases as the line length percentage increases. This is because the series impedance of the line varies proportionally with its length; thus, a greater distance from the sending node results in a higher impedance. It should be noted that the short-circuit level at node 5 is 2.7603 pu, corresponding to 0% of the line length, as previously mentioned.

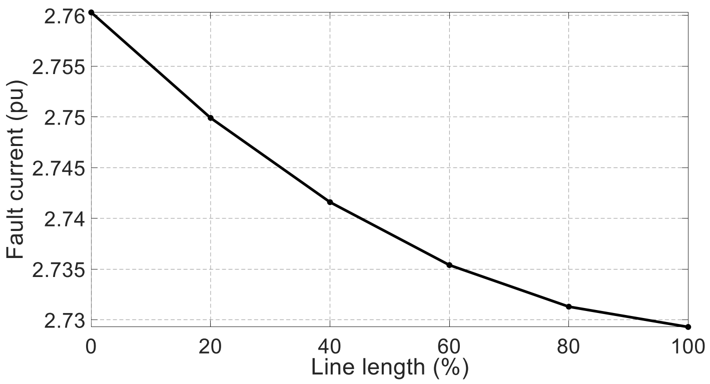

Fig. 2. Fault current along transmission line 5-4 as a function of its length percentage.

The reliability of the results of this study case can be demonstrated through a fault current balance in the transmission lines connected to the additional node 6, using the data presented in Table 2. It is important to note that the data in the mentioned table were obtained with the additional node located at 60% of the distance from the sending node.

Table 2. Symmetrical fault currents in the transmission lines connected in the fictitious node of the 5-node power system.

Sending node	**Reception node**	**Magnitude I_F (pu)**
5	**6**	1.5238
6	4	1.2116

By performing the fault current balance at node 6, a total current of 2.7354 pu is obtained, which exactly matches the total fault current value at 60% of the transmission line length connecting nodes 5 and 4, as shown in Table 1. Similarly, the correct current balance at each node of the power system used in this case study is verified. This confirms that the results of the proposed algorithm are reliable for calculating three-phase faults at any distance along a transmission line. The same technique was applied to a real power system, with the corresponding results presented below.

B. Study case: 39-node New England Power System

This case study verifies the reliability of the proposed algorithm for calculating symmetrical faults in larger power systems. The transmission line selected for analysis is connected between nodes 20-34 and the fictitious node 40 is added between these nodes to carry out the symmetrical fault analysis. The results of the symmetrical fault current at different percentages of the line length are shown in Table 3. The angle of the fault current is 90° in all cases.

Table 3. Symmetrical fault current on transmission line 20-34 at different distance percentages.

Line length (%)	**Magnitude I_F (pu)**
0	4.5636
20	4.5110
40	4.4606
60	4.4124
80	4.3663
100	4.3221

On the other hand, the behavior of the symmetrical fault current along the transmission line under analysis is shown in Fig. 3. As in the case study with the 5-node power system, in this case, the fault current decreases with increasing distance, maintaining a very similar behavior.

Regarding the behavior of the symmetrical fault current as a function of the distance from the transmission line, illustrated in Figures 2 and 3, it should be mentioned that such behavior is unique and different since it depends on the topology of the electrical power system, as well as on the values of the reactances of the transmission lines where the symmetrical fault is located. The reason for this is that the results of the case studies carried out with the power systems showed a unique and specific behavior for each line and for each power system, which makes it very difficult to predict due to the non-linearity of the power systems

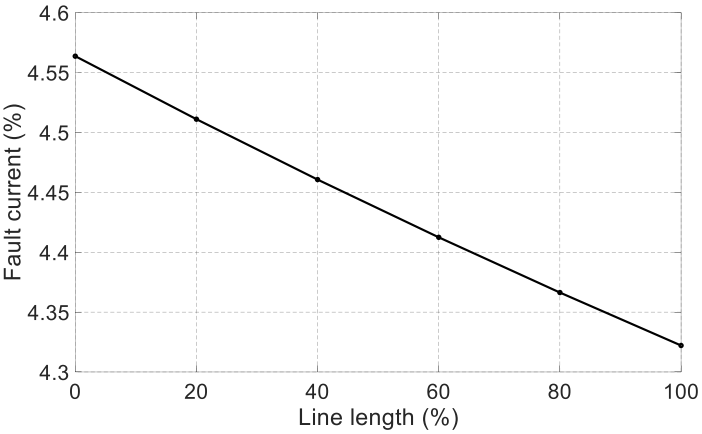

Fig. 3. Fault current along transmission line 20-34 as a function of its length percentage.

Table 4. Symmetrical fault currents in the transmission lines connected in the fictitious node of the 39-nodes power system.

Sending node	**Reception node**	**Magnitude I_F (pu)**
20	**40**	3.6904
40	34	0.7220

As in the case of the 5-node power system, the reliability of the results of this case study was demonstrated by balancing the fault current at the fictitious node 40, giving a total current at this node of 4.4124 pu, see Table 4. This agrees with the fault current at 60% presented in Table 2. It is clear that to perform the power balance at the fictitious node, it was placed at 60% of the transmission line.

V. CONCLUSIONS

An algorithm for the symmetrical faults calculation in power system transmission lines has been presented. The algorithm is based on the addition of a fictitious node to locate the fault at a desired distance along the line. The reliability of the algorithm was demonstrated using test and real power systems using a current balance at the point where the fault is located. The results of the study cases demonstrate that the algorithm can be reliably employed to compute and subsequently locate symmetrical faults in transmission lines of any power system. Furthermore, the algorithm has the potential to be modified and adapted to conduct studies for protection coordination of distance protection or to determine the short-circuit level of power system substations.

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